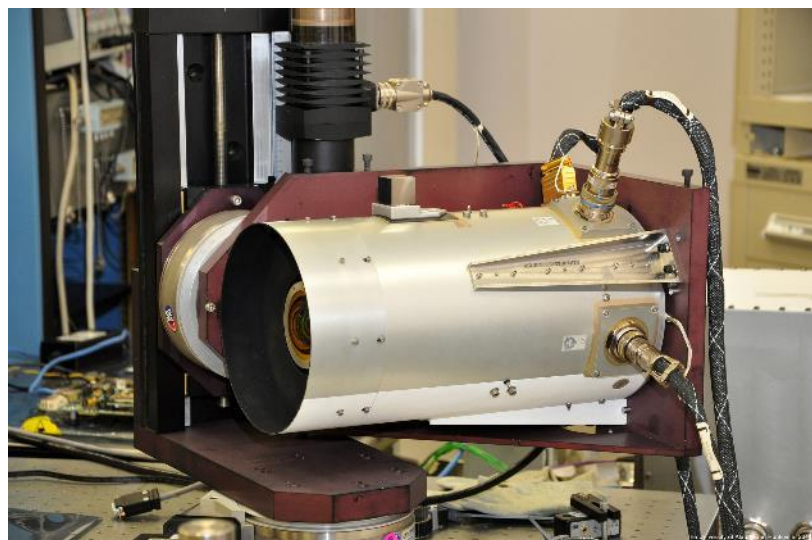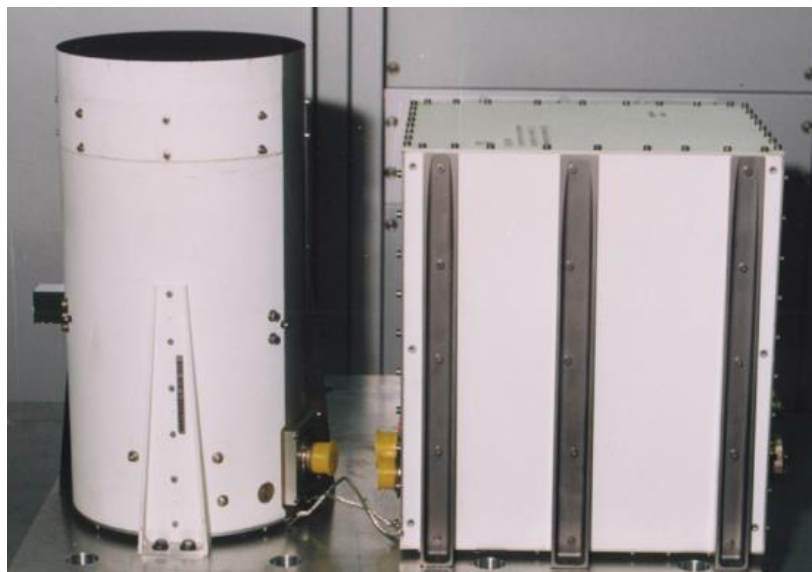National Aeronautics and Space Administration

Future lightning instruments for weather and climate monitoring from LEO

Patrick Gatlin, Mason Quick, Timothy Lang, Phillip Bitzer, Daniel Walker, William Koshak, Douglas Mach, Jackson Remington

NASA Marshall Space Flight Center, University of Alabama in Huntsville, USRA, ORAU/NPP

26th Satellite Meteorology, Climatology and Oceanography Conference
2024 American Meteorological Society Annual Meeting
January 29 – February 1, 2024

RIP

1995~2023

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Global Lightning Climatology
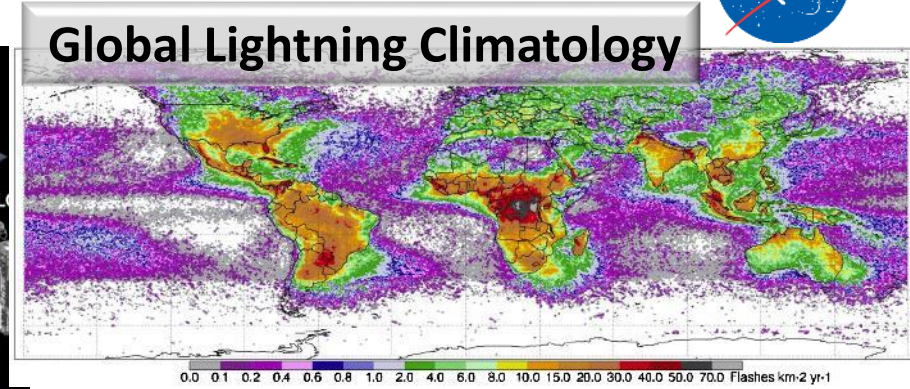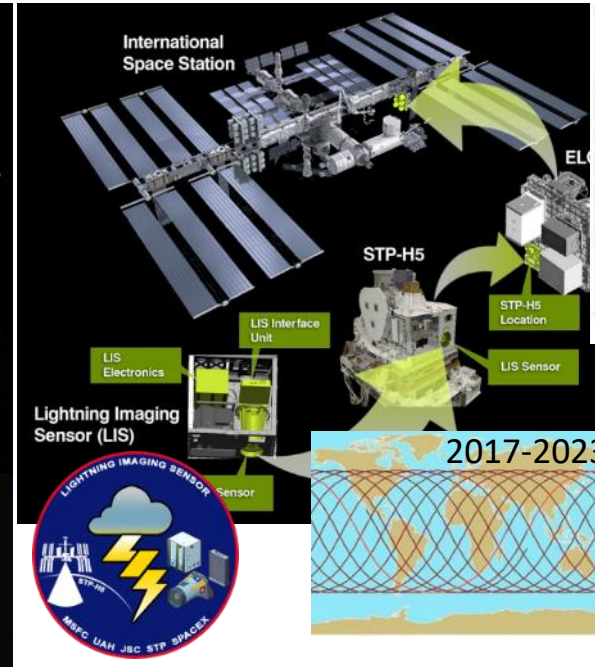
(Koshak 2017)

Annual Mean of LNOx

Derived from Satellite-based Lightning Observations

2017-2023
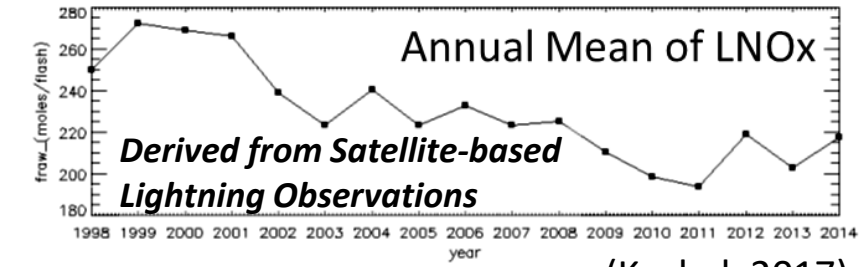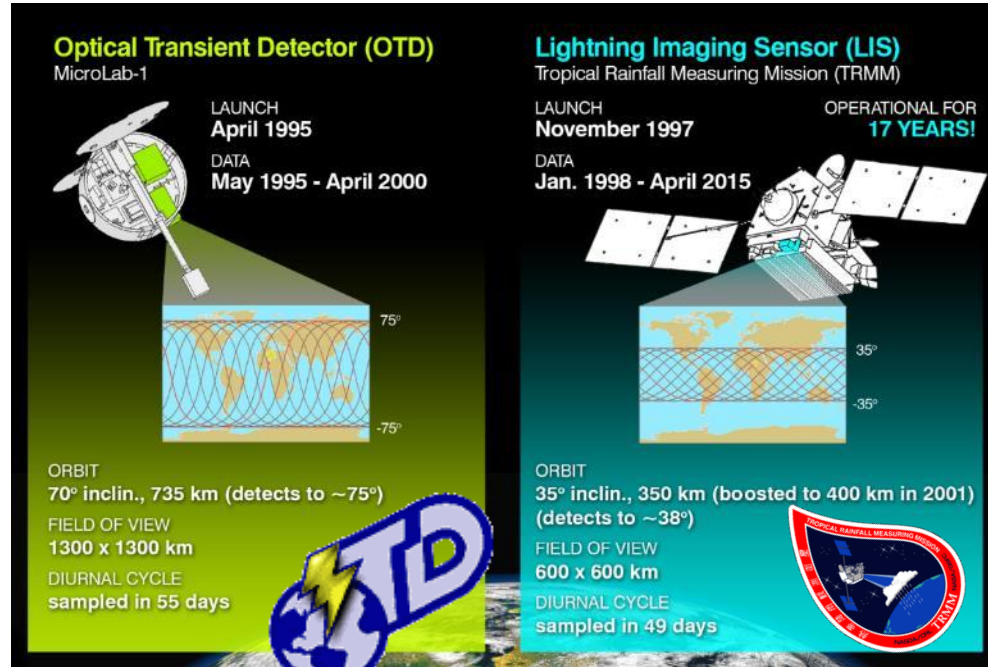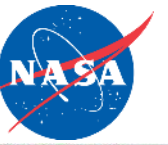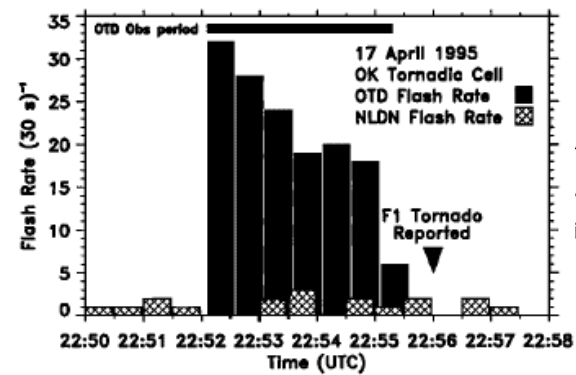
(Buechler et al. 2000)
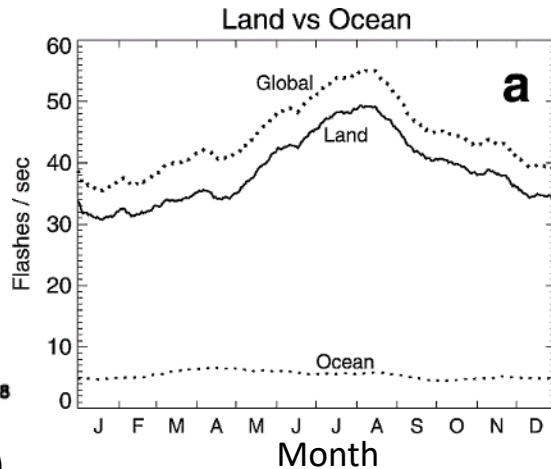
(Christian et al. 2003)

(Petersen et al. 2005)

(Williams et al. 2019)

…and drafting a new one to extend and enable novel applications

- **Extend the LEO-based climate record**
- **Cross-calibrator for GEO lightning mappers**
- ***Multispectral* mapping both night *and day***
- **Improve detection of lightning activity in severe storms**
- **3D mapping (proxy for updraft/mass flux, microphysics, LNOx)**

Remington et al., 2023: Simulated Feasibility of 3D Lightning Mapping from Space.
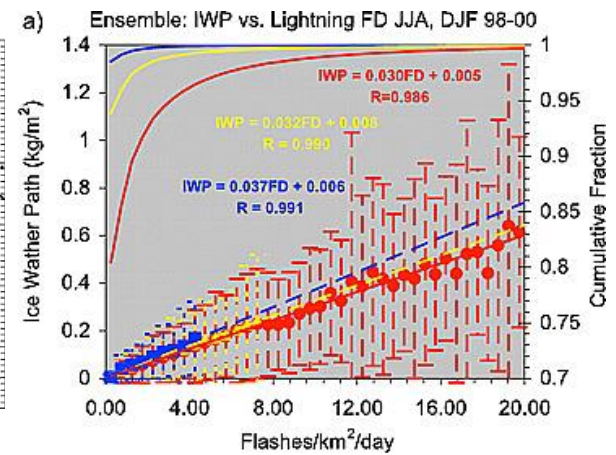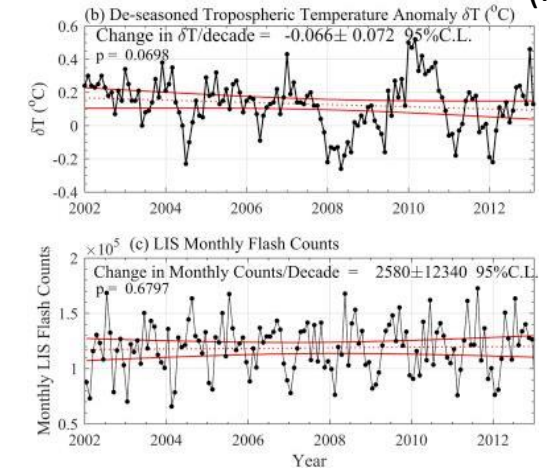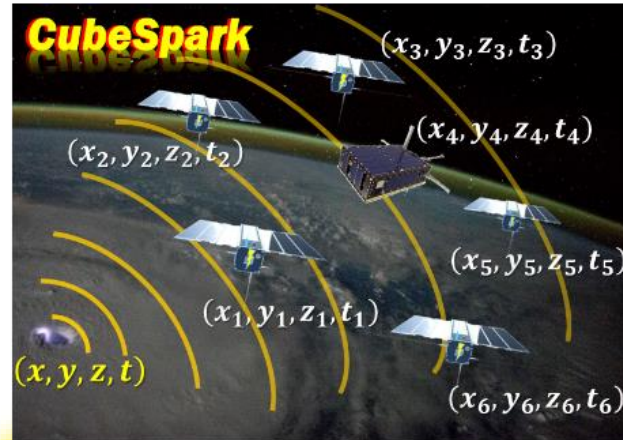*IEEE Trans. Geosci. Rem. Sens., in review.*

Monthly TRMM and ISS LIS Flash Rate
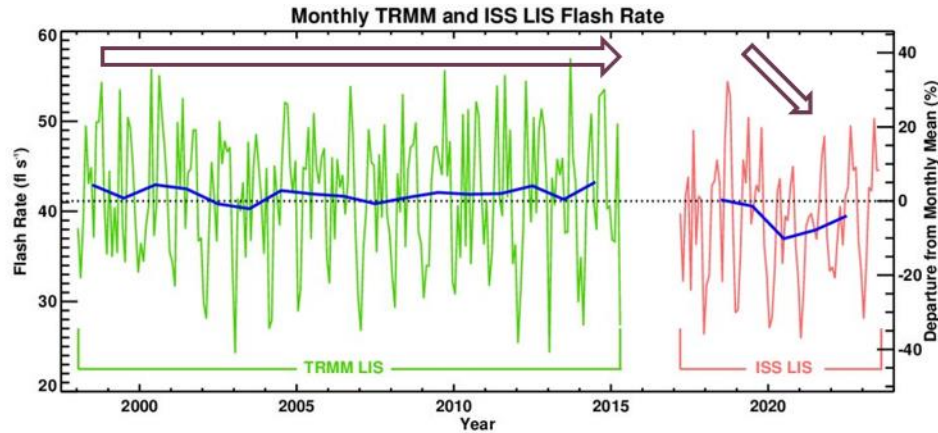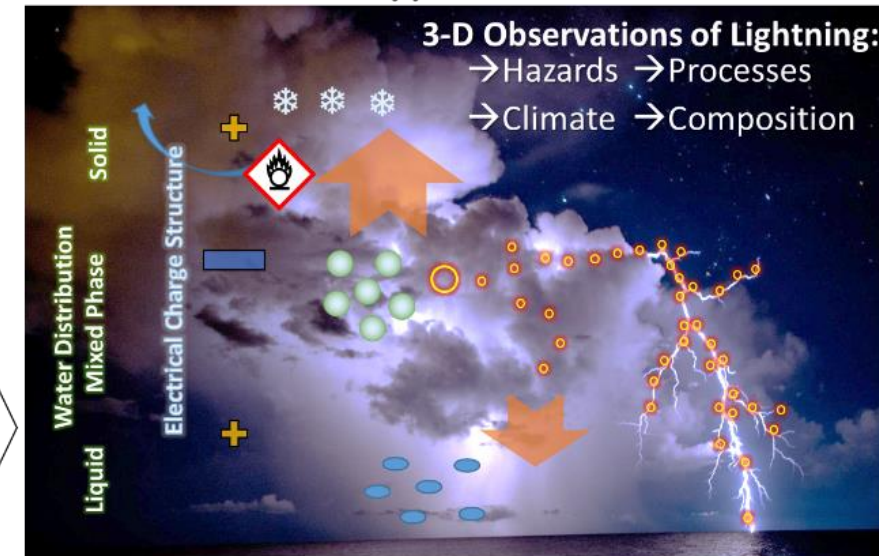
Coverage of GEO lightning mappers (2023)

CubeSpark — Measurement Concept

(x_1, y_1, z_1, t_1)
(x_2, y_2, z_2, t_2)
(x_3, y_3, z_3, t_3)
(x_4, y_4, z_4, t_4)
(x_5, y_5, z_5, t_5)
(x_6, y_6, z_6, t_6)
(x, y, z, t)

Bispectral Optical Detection

Extract lightning signals from VHF waveform measurements

Enabled Science and Applications

3-D Observations of Lightning:
→Hazards →Processes
→Climate →Composition

Water Distribution — Solid / Mixed Phase / Liquid
Electrical Charge Structure

Existing technologies give an incomplete depiction of lightning & thunderstorm processes

Coarse 2-D Pictures are great for general climatology and first order intensity assessments but fall short in resolving key details connecting thunderstorm processes with their effect on the surrounding environment

ISS LIS (4-km resolution)

GLM (8-km resolution)

Petersen et al. (2020)

GLM has difficulties detecting low altitude flashes in optically thick clouds

Rutledge et al. (2020)

GLM has difficulties detecting small, weak flashes
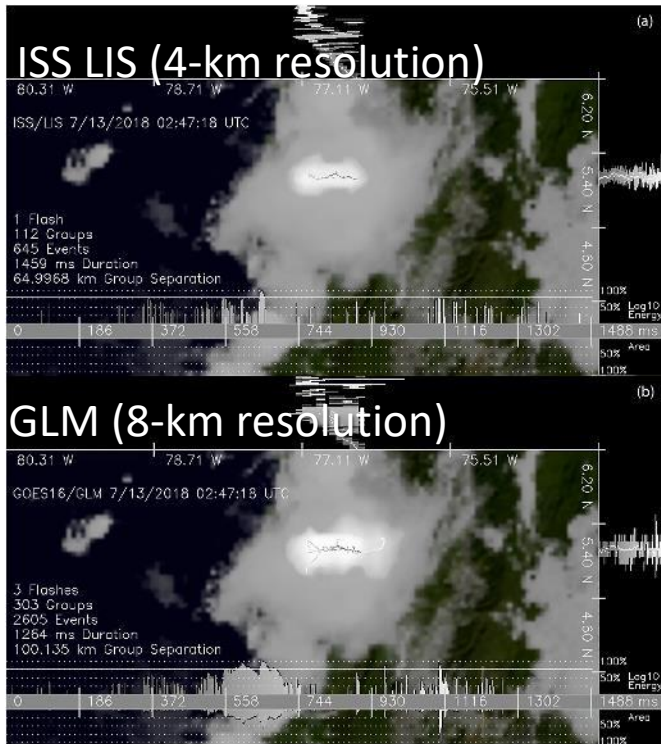
Zhang and Cummins (2020)
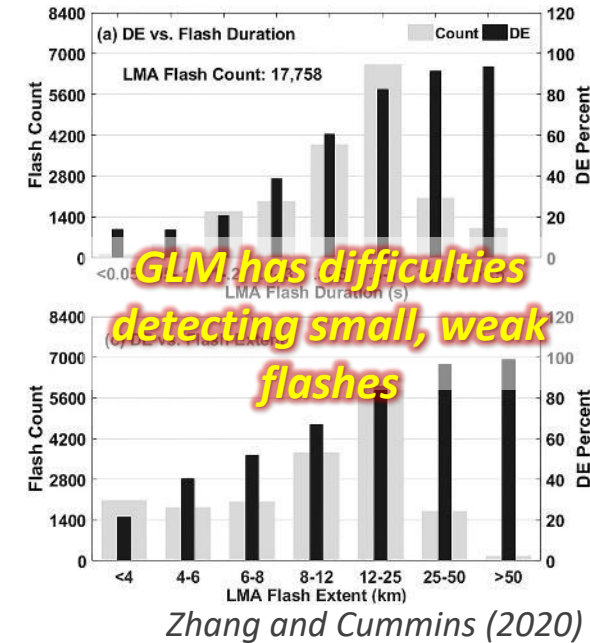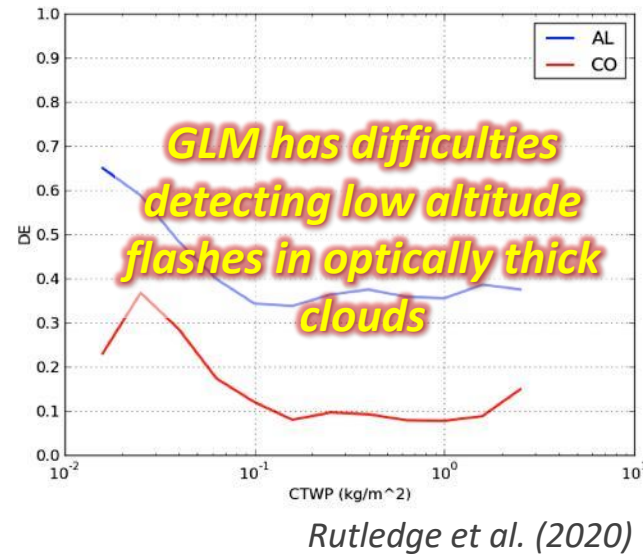
Implications:

- *Forecasting severe Weather/Thunderstorm impact*
- *Seasonal/regional variations of Water & Energy*
- *Distribution of LNOx (Atmos. Composition/Climate)*

Using multi-spectral fingerprints to detect more lightning

MMIA UV and NIR cameras

MMIA 2018-06-03T06:36:20.290591000 id:14343

Comparison of MMIA and ISS LIS

MMIA photom
LIS groups (dark grey)

ms; Origin: 2018-06-03T06:36:20.373791000

BLUE leads Red

Analysis by P. Bitzer (UAH)

- 14% of MMIA blue (337 nm) groups have no corresponding red (777 nm) group
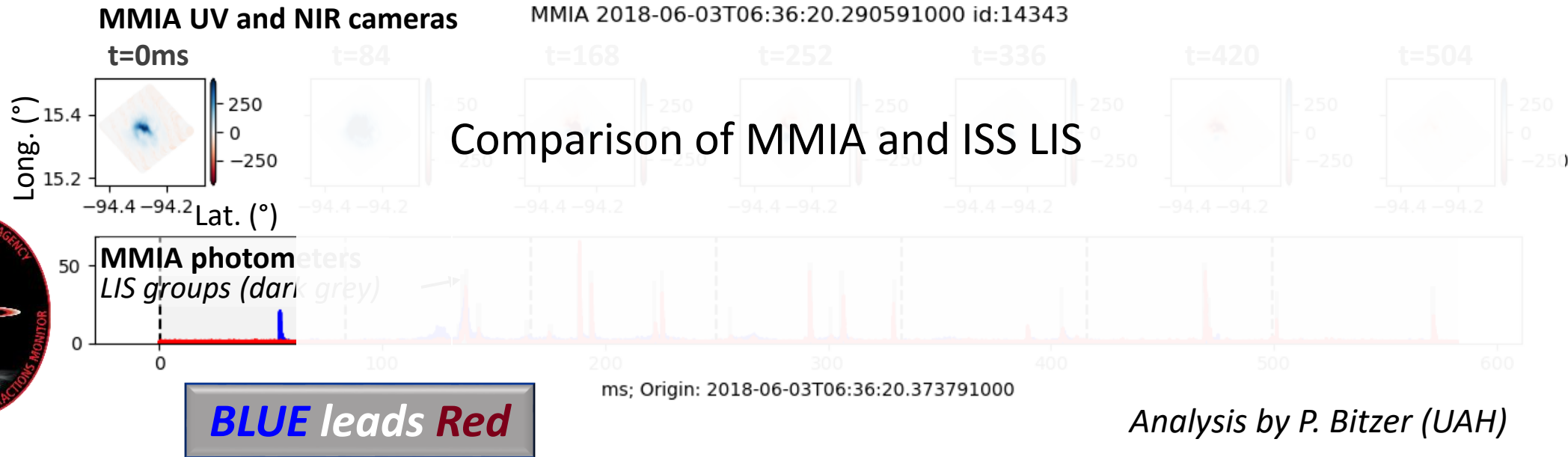
- 10-20% of ISS LIS groups have no corresponding MMIA blue group

- 337 nm emissions result from streamer discharges (i.e., early-stage lightning)

  ➢ Likely frequent intense regions of a storm

  ➢ Produce Nitrogen Oxides (LNOx), especially in upper troposphere

 ➢ Associated with energetic VHF discharges (NBEs) detectable from space

CubeSat Lightning Imaging and Detection Experiment (CLIDE)

- Objective: Improve the detection of small and optically dim lightning flashes that frequent intense thunderstorms

- Dual-wavelength:
  - 777.4-nm (OI multiplet—leaders)
  - 337-nm (N_2 SPS—streamers)

- Digital Imager and Event Detector:
  - CMOS Image Sensor developed for lightning detection
  - 432 x 420 pixel array (<2 km resolution from LEO)
  - 2000 frames per second
  - Enhance QE at 337-nm via backside processing (MBE+AR recipe)

- Being designed for use on small satellite missions (e.g., CubeSpark, Bushfire Monitoring)

- Funded by NASA ESTO-IIP21 as Instrument Concept Demo.

- Current TRL: 3

CLIDE Design Concept

777.4-nm

Digital Imaging & Event Detection Subsystem

337-nm
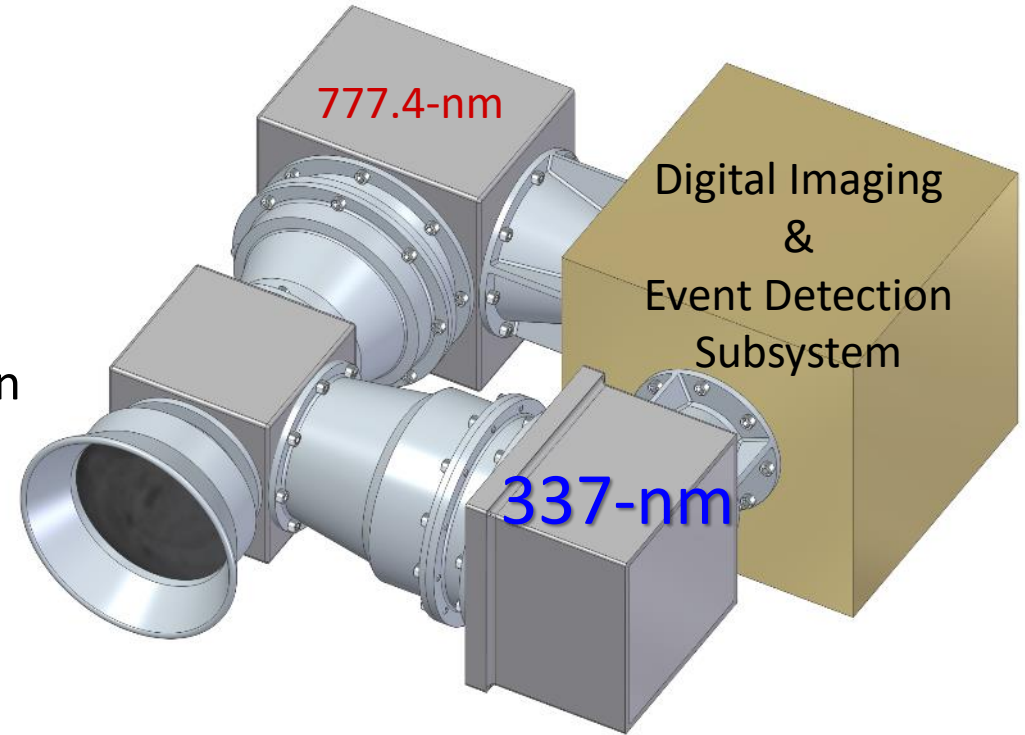
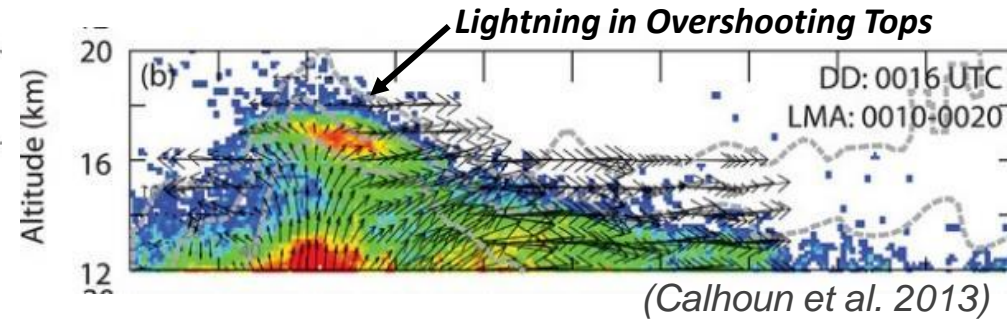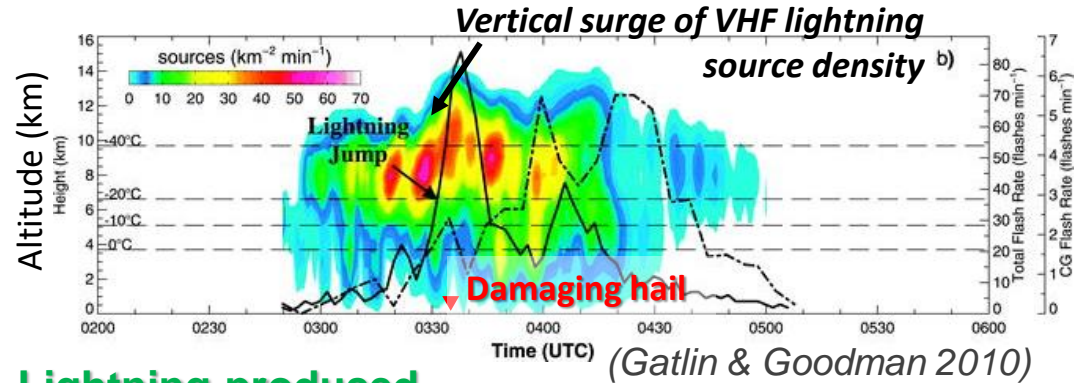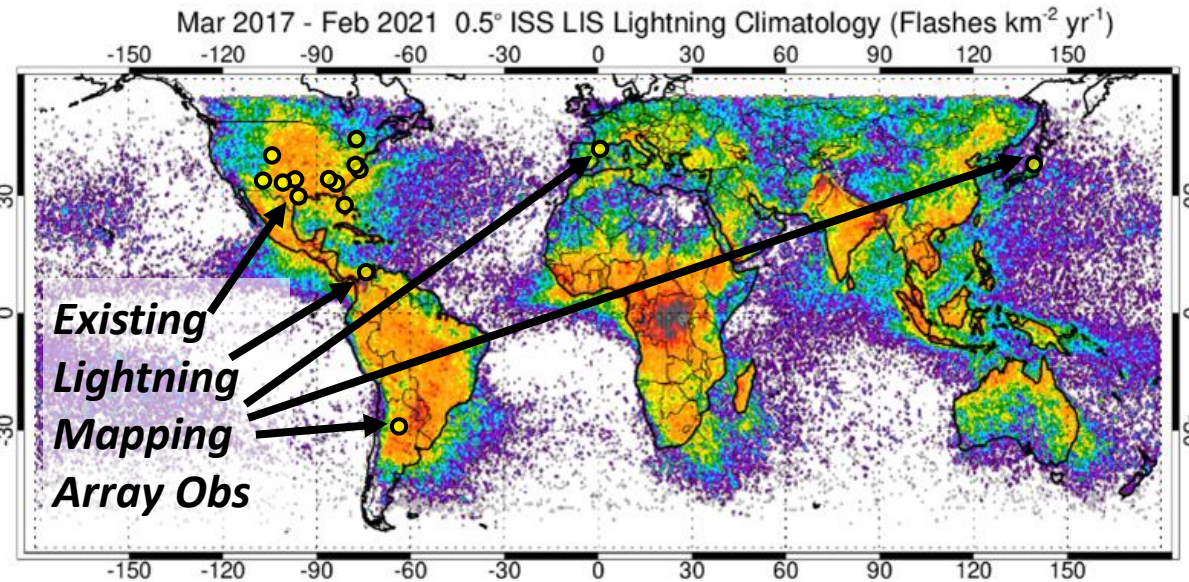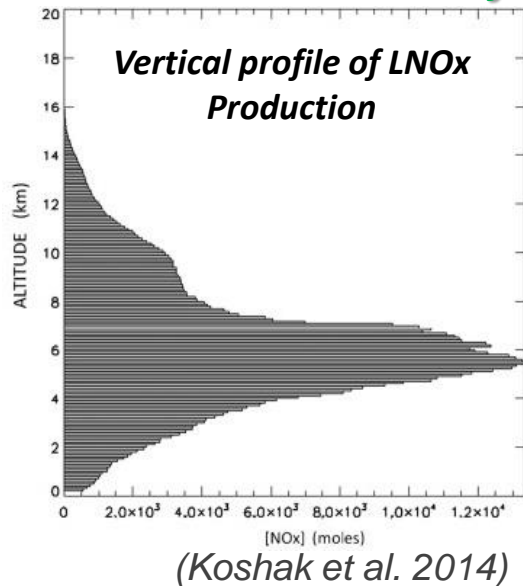*Single-channel design also exist for applications only needing 777-nm

Vertical observation is key to extracting vital information content from lightning

Storm Intensification and Severe Weather

Vertical surge of VHF lightning source density

Lightning Jump

Damaging hail

(Gatlin & Goodman 2010)

Lightning in Overshooting Tops

DD: 0016 UTC
LMA: 0010-0020

(Calhoun et al. 2013)

Lightning-produced Nitrogen Oxides and Impact on Climate / Air Quality

Vertical profile of LNOx Production

(Koshak et al. 2014)

Mar 2017 - Feb 2021   0.5° ISS LIS Lightning Climatology (Flashes km⁻² yr⁻¹)

Existing Lightning Mapping Array Obs

Anomalous Charge Storms and Flash Type/Polarity (important for hazard assessment)

Vertical distribution of VHF lightning source activity

(Lang et al. 2011)
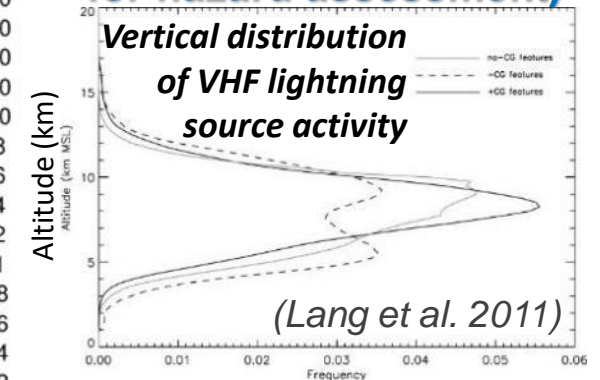
These studies enabled by 3D Observations of Lightning activity have been limited to regional networks

3-D monitoring of lightning with optical and VHF sensors

CubeSpark is a constellation of small satellites acting as a 3D lightning mapping network in space:
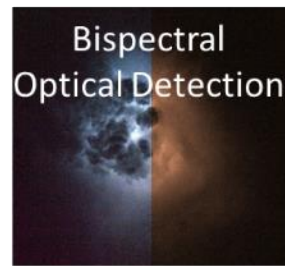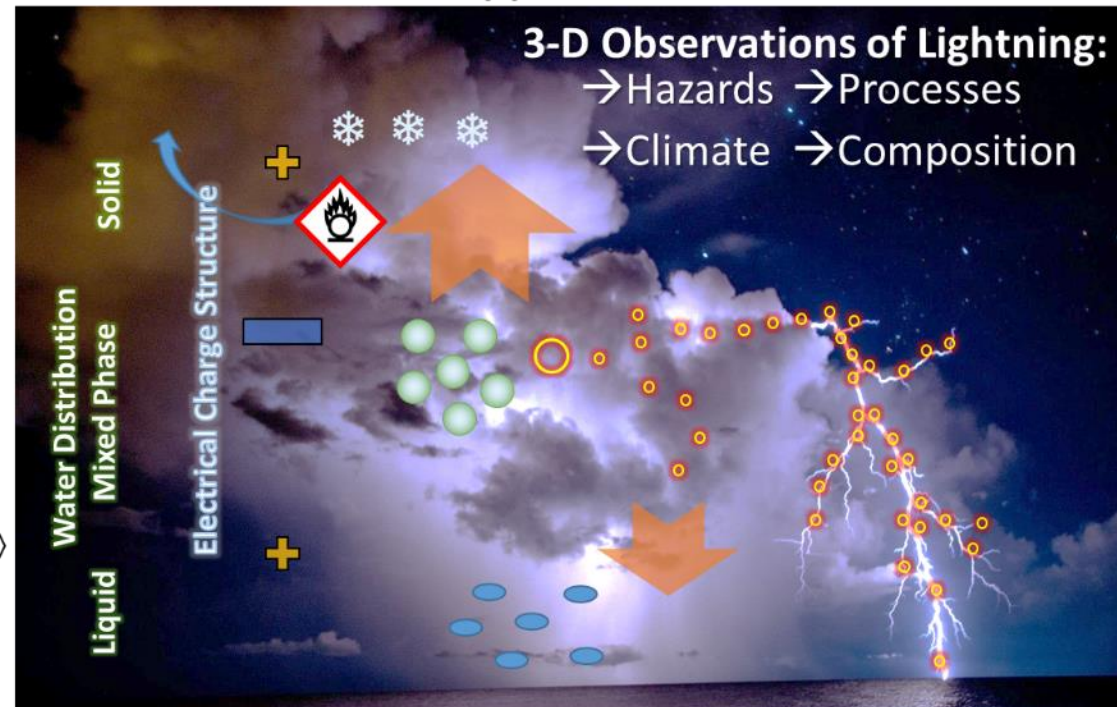- *VHF radio measurements to map lightning structure inside clouds*
- *Bispectral, high-resolution optical measurements to enhance detection of lightning in severe and anomalous thunderstorms and flashes that extend upward from cloud-top*

Measurement Concept

Enabled Science and Applications

Bispectral Optical Detection

CLIDE (MSFC)

Extract lightning signals from VHF waveform measurements

3-D Observations of Lightning:
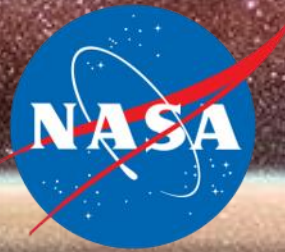→Hazards →Processes
→Climate →Composition

Water Distribution — Solid / Mixed Phase / Liquid

Electrical Charge Structure
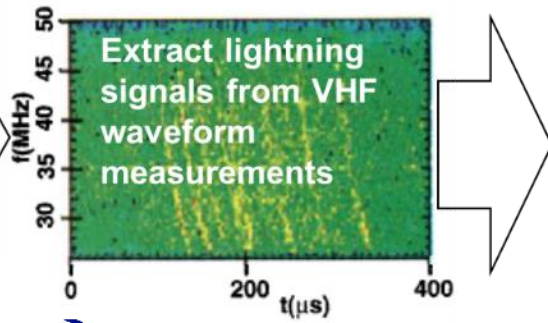
Observing System Simulation Experiment (OSSE) for Satellite-based Lightning

Nature Run
Cloud-Resolving Model with Explicit Electrification and Branching Scheme
Future: Chemistry

Uncertainties
- Forward Model
- Instrument

Forward Models
- Cloud Scattering (Optical)
- Ionospheric propagation (VHF)

Instrument Simulator
CLIDE (Optical)
VHF detector

Geophysical Variables
- Ice Water Content
- Updraft Location, Speed
- *LNOx*

Retrieval Algorithms
- Bayesian?
- Machine-learning?

Simulated Lightning Observations
- Cloud-top optical emission
- Flash altitude
- Flash length

Contact: Patrick.Gatlin@nasa.gov